Hadron-hadron correlations at low and high p_T in heavy-ion collisions

A. Majumder[a]

[a]Department of physics, Duke University, Box 90305, Durham, NC 27708.

The modification of two particle correlations within a jet due to its propagation through dense strongly interacting matter is explored. Different properties of the medium may be probed by varying the momentum of the detected hadrons. Very high transverse momentum (p_T) correlations sample the gluon density of the medium; the minimal modification on the same side as the trigger is consistent with the picture and parameters of partonic energy loss. Lower momentum hadrons, sensitive to the presence of composite structures in the medium may excite collective modes such as Cherenkov radiation, resulting in conical patterns in the detected correlations.

1. Introduction

The goal of ultra-relativistic heavy-ion collisions is the creation and study of excited strongly interacting matter, heated past a temperature beyond which confinement may no longer be expected [1]. Current experimental results from the Relativistic Heavy-Ion Collider (RHIC) demonstrate the formation of matter with bulk collective behaviour that is different from that observed in excited hadronic matter created at lower energy colliders. Such collectivity, manifested in the radial and elliptic flow of the produced matter is also different from what would have been expected from perturbative QCD calculations assuming a quasi-particle picture of the quark gluon plasma (QGP). The jet correlation analyses reported in these proceedings offers insight on two different characteristics of the produced matter. Very high momentum partons and radiated hard gluons [2] selectively sampled through the observation of high transverse momentum hadrons (referred to as hard-hard correlations) [3, 4] tend to sample the partonic substructure of the medium. Softer gluons radiated from such hard partons, due to their longer wavelengths, may interact strongly with the prevalent degrees of freedom in the medium. This modifies the dispersion relation of the gluons [5, 6] and may lead to non-jet-like correlations between a high momentum hadron and a softer hadron (referred to as hard-soft correlations) [7, 8].

2. Hard-Hard correlations

We commence with a study of the correlations between two hard particles on the same side. Such two-hadron correlations have been measured both in DIS [9] and high-energy heavy-ion collisions [3]. Within the energy ranges and angles explored, it is most likely that both these particles have their origin in a single jet which is modified by its interaction with the medium. Hence, such analysis requires the introduction of a dihadron

fragmentation function ($D_q^{h_1 h_2}$) [10], which accounts for the number of pairs of particles fragmenting from a jet. The modified dihadron fragmentation function in a nucleus is calculated in a framework similar to that for the modified single hadron fragmentation functions [11]. As a result, no additional parameters are required. Due to the existence of sum rules connecting dihadron fragmentation functions to single hadron fragmentation functions (D_q^h) [10], one studies the modification of the conditional distribution for the second rank hadrons,

$$R_{2h}(z_2) \equiv \int dz_1 D_q^{h_1,h_2}(z_1, z_2) \Big/ \int dz_1 D_q^{h_1}(z_1), \tag{1}$$

where z_1 and $z_2 < z_1$ are the momentum fractions of the triggered (leading) and associated (secondary) hadrons, respectively. This associated hadron correlation is found slightly suppressed in DIS off a nucleus versus a nucleon target and moderately enhanced or unchanged in central $Au + Au$ collisions relative to that in $p + p$ (in sharp contrast to the observed strong suppression of single inclusive spectra in both DIS and central $A + A$ collisions [12, 13]). Shown in the left panel of Fig. 1 is the predicted ratio of the associated hadron distribution in DIS off a nuclear target (N and Kr) to that off a proton, as compared to the experimental data from the HERMES collaboration at DESY [9]. The suppression of the associated hadron distribution $R_{2h}(z_2)$ at large z_2 due to multiple scattering and induced gluon bremsstrahlung in a nucleus is quite small compared to the suppression of the single fragmentation functions [12, 14]. The effect of energy loss seems to be borne, mainly, by the leading hadron spectrum.

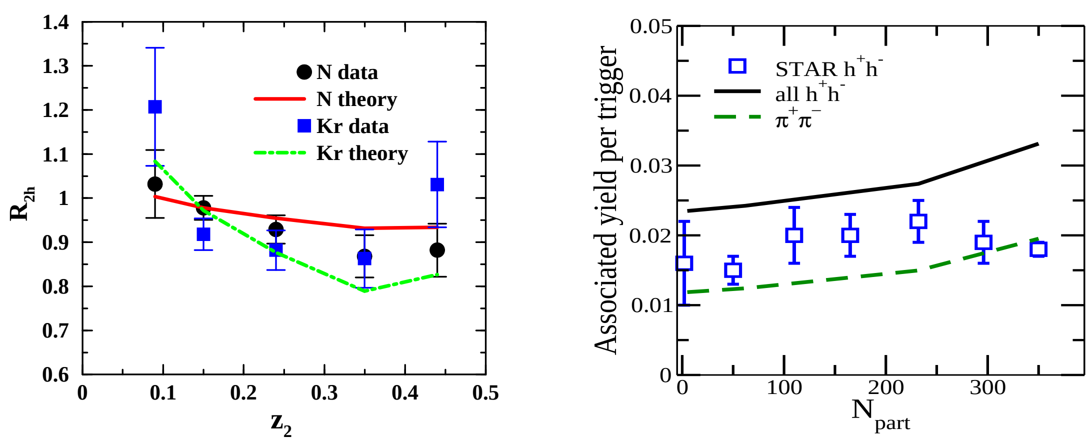

Figure 1. Results of the medium modification of the associated hadron distribution in a cold nuclear medium versus its momentum fraction (left panel) and versus system size in a hot medium (right panel) as compared to experimental data (see text for details).

In high-energy heavy-ion (or $p+p$ and $p+A$) collisions, jets are always produced in back-to-back pairs. Correlations of two high-p_T hadrons in azimuthal angle generally have two Gaussian peaks [3, 4]. The integral of the near-side peak (after background subtraction) over the azimuthal angle can be related to the associated hadron distribution or the ratio of dihadron to single hadron fragmentation functions [Eq. (1]. The calculation of this distribution requires an integration over the allowable initial jet energy weighted with the

corresponding production cross sections (obtained via a convolution of the initial structure functions and hard partonic cross sections [15, 16]). Experimental measurements quote an integrated yield over a range of $p_T^{\rm trig}$ and $p_T^{\rm assoc}$, divided by the cross section to produce a trigger hadron, integrated over the given range of $p_T^{\rm trig}$.

Computations of the associated yield, as function of the number of participants (N_{part}) are plotted in the right panel of Fig. 1 along with experimental data from Ref. [4]. In this plot, $p_T^{\rm trig}$ ranges from $8 - 15$ GeV while the associated momentum ranges from 6 GeV $< p_T^{\rm assoc} < p_T^{\rm trig}$. Unlike the case in DIS (left panel), the data are not normalized by the associated yield in $p + p$ collisions. As a result, the normalization is sensitive to the flavour content of the detected hadrons. The experimental results include all charged hadrons (with certain decay corrections [4]), whereas the theoretical predictions include two extreme possibilities: the lower dashed line denotes charged pions (π^+, π^-) inclusive of all decays and the upper solid line denotes $p, \bar{p}, K^+, K^-$ and π^+, π^- inclusive of all decays. The two cases bracket the experimental data, lending support to the framework of partonic energy loss. Decay corrections, which essentially involve removing contributions from unstable particle decays to the detected flavour content, will slightly reduce the plotted associated yields. While no trend may be discerned from the experimental measurements, the theoretical predictions show a slight enhancement with centrality due to increased trigger bias in more central collisions.

3. Hard-Soft correlations

For triggered events in central heavy-ion collisions, the Gaussian peak associated with the distribution of high p_T associated particles on the away side is almost absent. As the p_T of the associated particle is reduced, curious patterns emerge on the away side. A double humped structure is seen: Soft hadrons correlated with a quenched jet have a distribution that is peaked at a finite angle away from the jet [7, 8], whereas they peak along the jet direction in vacuum. The variation of the peak with the centrality of the collision indicates that this is not due to the destructive interference of the LPM effect. Such an emission pattern can be caused by Cherenkov gluon radiation [17], which occurs only when the permittivity for in-medium gluons becomes larger than unity ($\epsilon > 1$).

The existence of coloured bound states in a deconfined plasma [18], along with the assumption that these bound states have excitations which may be induced by the soft gluon radiated from a jet, allows for a large index of refraction. If the energy of the gluon is smaller than that of the first excited state, the scattering amplitude is attractive. As a result, the gluon dispersion relation in this regime becomes space-like ($\epsilon > 1$) and Cherenkov radiation will occur. This is simply demonstrated in a Φ^3 theory at finite temperature with three fields: ϕ a massless field representing the gluon and two massive fields Φ_1 and Φ_2 with masses m_1 and m_2 in a medium with a temperature T (see Ref.[5] for details). The resulting dispersion relations of the ϕ field for different choices of masses of Φ_1, Φ_2 are shown in Fig. 2 along with the corresponding Cherenkov angles of the radiation in the right panels. We obtain a space-like dispersion relation at low momentum which approaches the light-cone as the momentum of the gluon (p^0, p) is increased. The variation of the corresponding angles may be actually detectable in current experiments. Even though we have studied a simple scalar theory, the attraction leading to Cherenkov-like

bremsstrahlung has its origin in resonant scattering. Thus, the result is genuine and only depends on the masses of the bound states and their excitations. Further experimental and theoretical investigations into such correlations may allow for a possible enumeration of the degrees of freedom in the produced excited matter.

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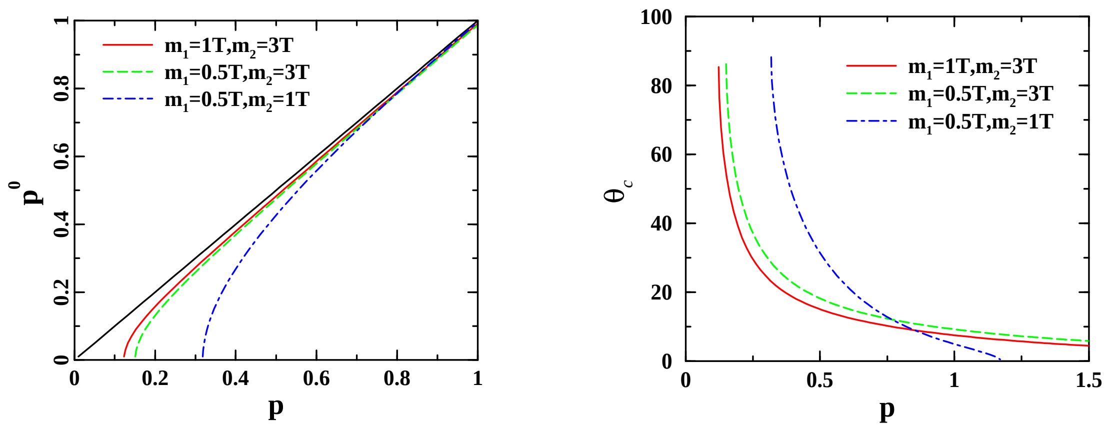

Figure 2. The left panel shows the dispersion relation of ϕ in a thermal medium with transitional coupling to two massive particle. The right panel shows the corresponding Cherenkov angles versus the three momentum of the gluon.

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